

## SUPERSYMMETRY IN THE VERY EARLY UNIVERSE\*

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Supersymmetric flat directions can have a number of important consequences in the very early universe. Depending on the form of the SUSY breaking potential arising from the finite energy density at early times, coherent production of scalar condensates can result along such directions. This leads a cosmological disaster for Polonyi type flat directions with only Planck suppressed couplings, but can give rise to the baryon asymmetry for standard model flat directions. Flat directions are also natural candidates to act as inflatons. Achieving density fluctuations of the correct magnitude generally requires an additional hidden SUSY breaking sector.

### 1. Introduction

At present, supersymmetry seems to provide the most likely solution to the problem of the large hierarchy between the weak and GUT or Planck scales. As there is yet no direct experimental evidence for supersymmetry, it is worth turning to the early universe for possible signatures. In this review I will describe some recent progress in understanding effects of supersymmetry in the *very* early universe. Here the relevant measure for the epoch of the early universe will be the Hubble constant. Most of the important effects discussed below will be for  $H > 100$  GeV. (This is to be compared with, for example, the electroweak phase transition which takes place when  $H \sim 10^{-12}$  GeV). At such high energy scales we almost certainly don't know the full spectrum or interactions. In order to glean any information there must be some affects associated with a generic feature of supersymmetric theories, which is not shared by non-supersymmetric theories. Flat directions are just such a general feature of supersymmetric theories. As described in more detail below, flat directions can lead to the coherent production of scalar condensates. These condensates can have important consequences, including the production of the baryon asymmetry. In addition, flat directions are natural candidates to act as inflatons. This generally requires an additional sector which breaks supersymmetry at a high scale. These considerations may even give some hints to possible cosmological selection principles for the type of vacuum in which we live.

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Flat directions are directions in field space on which the perturbative potential exactly vanishes. Such directions arise essentially as accidental classical degeneracies. Supersymmetric theories are special in that the non-renormalization theorem guarantees that these degeneracies are not lifted at any order in perturbation theory. Without supersymmetry in general an accidental degeneracy would be lifted quantum mechanically. Flat directions are quite common in supersymmetric theories. For example, in the minimal supersymmetric standard model there is a 37 complex dimensional subspace of the full field space on which the scalar gauge potential vanishes. In this subspace there are 100's of rays on which the renormalizable potential arising from Yukawa couplings vanishes. In string theory flat directions are also common. The internal manifold on which the two dimensional fields live often depends on a continuous set of parameters,  $\mathcal{M}(\phi)$ , which leave the theory conformally invariant. Geometrically the  $\phi$  may be thought of as deformations of  $\mathcal{M}$ . The operators which describe the deformations are exactly marginal, and so in four dimensions appear as exactly flat directions. The space of all flat directions in a theory is usually referred to as the moduli space.

Fields coupled by renormalizable interactions gain a large mass along flat directions. The moduli space therefore contains the relevant degrees of freedom to describe the evolution of fields in the early universe.

## 2. Supersymmetry Breaking in the Early Universe

Important for all the cosmological effects discussed below is the potential along flat directions. As it is supersymmetry which protects an exact flat direction from obtaining a potential, in the presence of SUSY breaking a potential results. Throughout I will make a hidden sector assumption in which the intrinsic SUSY breaking is transmitted to flat directions only through gravitational strength interactions. This turns out to be justified far out along flat directions even if there are other interactions (except in special cases). The general form of the soft SUSY breaking potential is then

$$V(\phi) = m^2 M_p^2 \mathcal{F}(\phi/M_p) \quad (1)$$

where  $\phi$  parameterizes the flat direction,  $M_p$  is the Planck mass,  $m \sim \Lambda^2/M_p$  is the soft SUSY breaking mass, and  $\Lambda$  is the intrinsic SUSY breaking scale. Under the assumptions given above, in the present universe  $\Lambda_{\text{now}} \sim 10^{11}$  GeV in a hidden SUSY breaking sector, giving  $m \sim m_{3/2} \sim 10^2 - 10^3$  GeV. However in the early universe SUSY breaking can arise from other sources. In particular the finite energy density,  $\rho$ , necessarily generates a SUSY breaking potential along flat directions with  $\Lambda_\rho^2 \sim \sqrt{\rho}$ .<sup>1</sup> Using the relation between  $H$  and  $\rho$  for an expanding background,  $\rho = 3H^2 M_p^2$ , implies that  $m \sim H$  for  $H$  above the weak scale.<sup>1,2</sup> In general, the specific functional form of the potential from this source does not coincide with that from hidden sector SUSY breaking. This has important implications for the coherent production of

condensates, as described in the next section. Also, the existence of another hidden sector with  $\Lambda \sim 10^{16}$  GeV can lead to successful inflation along flat directions as discussed in section 4.

### 3. Coherent Production of Scalar Fields

The evolution of a flat direction in the early universe is determined by the classical equations of motion. The equation of motion for the average value of  $\phi$  is

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0 \quad (2)$$

The damping term, proportional to  $H$ , arises because of the expanding background. For  $H^2 \gg V''$  the field is overdamped, while for  $H^2 \ll V''$  it is underdamped. Previously, it had been implicitly assumed that the potential along a flat direction was set by hidden sector SUSY breaking, i.e.  $V'' \sim m_{3/2}^2 \sim (100 \text{ GeV})^2$ . If this were the case, then at early times the field would be highly overdamped and effectively frozen. Since the hidden sector potential is much smaller than the relevant mass scale at very early times, it would seem reasonable to assume that the initial value of the fields along a flat direction is random. When the Hubble constant decreases to  $H \sim m_{3/2}$ , the field would begin to oscillate freely about a minimum of the potential. These oscillations redshift like matter and amount to a coherent condensate of nonrelativistic particles. Since flat directions are a generic feature of supersymmetric theories, the production of scalar condensates in the early universe would also seem to be a generic feature. A number of questions about this scenario immediately arise however. Among these are the questions of initial conditions and the form of the potential along flat directions at early times.

The SUSY breaking potential arising from the finite energy density has an important effect on the production of condensates, and helps to answer the questions raised above. Since  $m \sim H$  at early times, rather than being highly overdamped, the field is always parametrically near critically damped. During inflation when  $H$  is roughly constant, the field is then driven very efficiently to an instantaneous minimum of the potential. However, the typical scale of variation in the soft potential is  $M_p$ . So the minimum of the finite density induced potential is in general displaced by  $\mathcal{O}(M_p)$  from the true minimum for a direction which is exactly flat in the SUSY limit. For a direction which is lifted by non-renormalizable terms in the superpotential,  $\phi \ll M_p$  just on energetic grounds, but large displacements can still occur. In either case, when  $H \sim m_{3/2}$  the field then begins to oscillate in the true potential with a large “initial” expectation value and a condensate is formed. The subsequent evolution of the condensate depends on its quantum numbers and couplings. Two examples are the production of a condensate of Polonyi type moduli, and the generation of a

baryon asymmetry along flat directions of standard model fields.

### 3.1. The Polonyi Problem

Polonyi fields are flat directions which are exactly flat in the supersymmetric limit and have only gravitational strength couplings to light fields. Fields of this type are common in hidden sector models of SUSY breaking, and the moduli of string theory fall in this class. Since these directions are exactly flat in the SUSY limit, as discussed above, the finite density induced potential in general causes the fields to be displaced by  $\mathcal{O}(M_p)$  from the true minimum. The resulting condensate then dominates the energy density essentially as soon as free oscillations begin when  $H \sim m_{3/2}$ . Since the condensate has only Planck suppressed interactions its lifetime is quite long,  $\tau \sim 8\pi^2 M_p^2/m^3 \sim 10^4$  s. This leads to a number of cosmological problems. The decay takes place during and after the era of nucleosynthesis. Photodissociation and photoproduction modifies the light element abundances in an unacceptable manner. In addition, if the LSP is stable, the relic density is far too large. Finally, because of the large entropy release, baryogenesis must take place during or after the decay. The production of Polonyi condensates is obviously a cosmological problem which must be avoided in some way.

There have been a number of suggestions to solve the Polonyi problem. If the minimum of the finite density induced potential happened to coincide with the true minimum arising from hidden sector SUSY breaking, the moduli would be driven to a stationary point during inflation, and no condensate would result after inflation.<sup>1,2</sup> This is technically natural if there is a point of enhanced symmetry on moduli space.<sup>1</sup> The potential is always extremum about such points and could be a minimum at both early and late times if the enhanced symmetry remains unbroken (aside from possible weak scale breaking now). Such points are in fact common in string theory, and are analogous to the self dual radius for toroidal compactification. For the dilaton the only candidate for such a symmetry seems to be  $S$  duality. However, at the dilaton self dual point the four dimensional gauge coupling is likely to be very large. So if symmetries are the solution to the Polonyi problem, the dilaton is probably on a different footing. Another possibility is that the dangerous Polonyi directions gain a mass from SUSY preserving dynamics at a high scale, and therefore decay at an early epoch. This solution is natural in the context of moduli inflation (described in section 4) which requires an additional dynamical sector to drive inflation.<sup>3</sup> Again the dilaton is problematic within this solution. Since SUSY breaking and the superpotential in the sector responsible for driving inflation must vanish at the minimum of the inflaton potential, the dilaton potential at late times can not arise from this sector.<sup>3</sup> The only known exceptions to this are racetrack schemes which stabilize the dilaton through a balance between multiple dynamical sectors.<sup>4</sup> Another possibility is that a brief period of late inflation sufficiently dilutes the Polonyi fields, while retaining density

fluctuations on large scales.<sup>5</sup>

Lyth and Stewart have recently suggested a version of late inflation which has a number of desirable features.<sup>6</sup> The main assumption is that a flat direction has a potential (arising from hidden sector SUSY breaking) with a minimum at some scale  $M \ll M_p$ , and that the cosmological constant vanishes at this minimum. The scale  $M$  might be associated with a GUT or intermediate scale. In addition the origin ( $\phi = 0$ ) is assumed to be a maximum for this direction. Now at high temperatures the minimum of the free energy can reside at the origin. This can occur if additional states become massless, thereby increasing the entropy contribution. So at early times it is possible for the flat direction to be held at the origin by thermal effects. From the form of the potential (1), and with the assumptions spelled out above, there is a constant contribution to the vacuum energy at this point on moduli space of  $V_0 \sim m_{3/2}^2 M^2$ . Once the energy density of the Polonyi condensate and thermal plasma drop below this value, the universe enters a period of inflation with Hubble constant  $H \sim m_{3/2} (M/M_p)$ . The temperature drops as the thermal plasma is diluted during inflation. When  $T \sim m_{3/2}$  the thermal effects no longer trap the flat direction at the origin, and inflation ceases. The flat direction then begins to oscillate about the true minimum. These oscillations eventually decay to standard model fields through non-renormalizable operators suppressed by the scale  $M$ . In order for the decays to take place before the era of nucleosynthesis,  $M$  probably can not be associated directly with the GUT scale, but could be related to an intermediate scale.<sup>7</sup> The total number of  $e$ -foldings during inflation is  $N \sim \ln(T_i/m_{3/2})$  where  $T_i$  is the temperature when  $V_0$  dominates the energy density,  $g_* T_i^3 T_R \sim m_{3/2}^2 M^2$ , and  $T_R$  is the reheat temperature from an earlier standard inflation.<sup>7</sup> Under reasonable assumptions,  $N$  is large enough to sufficiently dilute the Polonyi fields, but small enough to avoid eliminating primordial density fluctuations on large scales. This type of inflation seems to be unique in that it necessarily undergoes a small number of  $e$ -foldings, and so is well suited to solve the Polonyi problem. Since no fields undergo Planck scale excursions, and  $H \ll m_{3/2}$  during this inflation, the form of the moduli potential essentially coincides with the true potential, and the Polonyi fields are driven to the true minimum. Gravitinos are also diluted by this late inflation. Because of the large dilution, baryogenesis probably has to take place in the decay of the oscillating flat direction after inflation. This last requirement probably requires the explicit or spontaneous breaking of  $R$  parity.<sup>7,8</sup>

### 3.2. Baryogenesis Along Flat Directions

Individual flat directions necessarily carry a global quantum number. For standard model flat directions the possibility therefore exists to store a net baryon number in a condensate. The production of a net asymmetry in a condensate depends on the magnitude of the  $B$  violating terms in the potential when the direction begins to

oscillate freely ( $H \sim m_{3/2}$ ). Affleck and Dine originally suggested this as a mechanism of baryogenesis.<sup>9</sup>

Standard model directions which are flat at the renormalizable level will in general be lifted by non-renormalizable interactions in the superpotential,

$$W = \frac{\lambda}{nM^{n-3}}\phi^n \quad (3)$$

where  $\phi$  parameterizes the direction made of  $n$  standard model fields, and  $M$  is some large mass scale such as the GUT or Planck scale. Given the discussion of finite density SUSY breaking in section 2, the relevant part of the potential along  $\phi$  is

$$V(\phi) = (cH^2 + m_\phi^2)|\phi|^2 + \left( \frac{(A + aH)\lambda\phi^n}{nM^{n-3}} + h.c. \right) + |\lambda|^2 \frac{|\phi|^{2n-2}}{M^{2n-6}} \quad (4)$$

where  $m_\phi \sim A \sim m_{3/2}$  are soft parameters arising from hidden sector SUSY breaking, and  $c \sim a \sim \mathcal{O}(1)$  are the soft parameters induced by the finite energy density.<sup>10</sup> The  $A$  term (proportional to  $W$ ) has the important effect of violating  $B$  and has a definite  $CP$  violating phase relative to  $\phi$ . Notice that the question of an enhanced symmetry point does not arise for standard model flat directions. The origin is always a symmetry point and the potential is an extremum there. If  $c > 0$  the field gets driven to the origin during inflation and no condensate forms. However, if  $c < 0$  the minimum at early times lies at  $|\phi| \sim (HM^{n-3}/\lambda)^{1/(n-2)} \ll M_p$ . During inflation the field gets driven very close to this value. After inflation  $H$  decreases and the instantaneous value of the minimum decreases in time. The field tracks close to this value during this epoch. Eventually when  $H \sim m_{3/2}$  the  $m_\phi^2$  term from hidden sector SUSY breaking dominates, and the field begins to oscillate about the new minimum at  $\phi = 0$ . However, just at this time the magnitude of the  $A$  term is necessarily the same order as the other terms in the potential. A near maximal asymmetry (depending precisely on the initial phase of  $\phi$ ) therefore results in the condensate.<sup>10</sup> Note that this is *independent* of the magnitude non-renormalizable operator which lifts the flat direction, and any initial condition assumptions.

Even though the fractional asymmetry is largely independent of any details, the total density in the condensate depends on the order at which the flat direction is lifted. In addition, the relevant quantity is the baryon per entropy ratio. Putting everything together,  $n_b/s$  depends mainly on the reheat temperature after inflation,  $T_R$ , and the order at which the direction is lifted

$$\frac{n_b}{s} \sim \epsilon \frac{T_R}{m_\phi} \left( \frac{m_{3/2}M^{n-3}}{\lambda M_p^{n-2}} \right)^{2/(n-2)} \quad (5)$$

where  $\epsilon \sim \mathcal{O}(1)$  is the condensate asymmetry, and the quantity in brackets is the ratio  $\rho_\phi/\rho_{tot}$  when  $\phi$  begins to oscillate freely. Unless  $T_R$  is near the weak scale,  $n_b/s$  is too large for  $n \geq 6$  without additional entropy releases. However for  $n = 4$  a reasonable

value results,  $n_b/s \sim 10^{-10}(T_R/10^9 \text{ GeV})(M/\lambda M_p)$ . In the MSSM with conserved  $R$  parity,  $LH_u$  is the unique renormalizable flat direction which is lifted at  $n = 4$  and which carries  $B - L$  (the non-anomalous combination of  $B$  and  $L$ ). This direction is also special in that it is the only one which has a  $H_u$  component, and is therefore perhaps the most likely to develop a negative mass squared in the early universe from renormalization group evolution (because of the large top quark Yukawa). The operator which lifts this direction,  $W = (\lambda/M)(LH_u)^2$ , is responsible at low energies for neutrino masses. So in this scenario the baryon asymmetry is related to lightest neutrino mass,  $n_b/s \sim 10^{-10}(T_R/10^9 \text{ GeV})(10^{-5} \text{ eV}/m_\nu)$ .

It is also possible to obtain a baryon asymmetry from non-standard model flat directions. In fact, if a condensate decays through non-renormalizable operators which couple to  $R$ -odd combinations of standard model fields, both a baryon asymmetry and relic LSPs can be produced.<sup>8</sup> In this scenario the baryon and dark matter densities have the natural relation  $\Omega_b/\Omega_{\text{LSP}} \sim m_b/m_{\text{LSP}}$ . Assuming closure density, limits on the baryon density from nucleosynthesis then give an upper limit on the LSP mass in this scenario,  $m_{\text{LSP}} < 100h^2 \text{ GeV}$ , where  $h = H/(100 \text{ km s}^{-1} \text{ Mpc}^{-1})$ .<sup>8</sup>

#### 4. Inflation Along Flat Directions

The existence of an inflationary phase in the early universe eliminates the flatness and horizon problems of standard big bang cosmology. In addition, quantum deSitter fluctuations of the inflaton field driving inflation give rise to a (nearly) scale invariant spectrum of density fluctuations, which can act as seeds for structure formation. In order to be consistent with density and temperature fluctuations in the present universe,  $\delta\rho/\rho \sim \delta T/T \sim 10^{-5}$ , the inflaton potential must be extremely flat, with a very small dimensionless self coupling,  $\lambda \sim 10^{-8}$ . Since the potential for moduli are exactly flat in the supersymmetric limit, these fields seem to be natural candidates to act as inflatons.<sup>11,12,13</sup> A nontrivial vacuum energy (as required for inflation) over moduli space requires SUSY breaking. The most straight forward way in which this can arise is for there to be nontrivial moduli dependence of a SUSY breaking scale,  $\mu$ , in some sector. Assuming only Planck scale couplings between this SUSY breaking sector and moduli, the form of the moduli potential is then

$$V(\phi) = \mu^4 \mathcal{F}(\phi/M_p) \quad (6)$$

The small self coupling arises from the ratio of mass scales,  $\lambda \sim (\mu/M_p)^4$ . The correct magnitude for density and temperature fluctuations results for  $\mu \sim 10^{16} \text{ GeV}$ , giving a Hubble constant during inflation of  $H \sim 10^{14} \text{ GeV}$ . With the form of the potential (6) the power in gravitational waves is naturally much smaller than that in scalar perturbations.

It is often remarked that the small self coupling of inflaton potentials amounts to extreme fine tuning. However, here  $\mu$  arises from dynamical SUSY breaking as

the result of dimensional transmutation, and can be hierarchically smaller than the Planck scale. No fine tuning is required (aside from the moderate amount of tuning to achieve slow roll so that the vacuum energy dominates the kinetic energy during inflation). It is even possible for the inflaton to have renormalizable couplings to other fields. The non-renormalization theorem guarantees that even in the presence of such large couplings, the form of the potential (6) is not modified. Flat directions in standard model fields could even act as inflatons.<sup>5,12</sup>

In order for moduli to act as inflatons with a SUSY breaking potential of the scale given above, a number of interesting requirements must be met. The first is that SUSY breaking in the sector responsible for driving inflation should vanish at the minimum of the moduli potential, i.e.  $DW(\phi_0) = 0$  where  $W$  is the nonperturbative superpotential generated over moduli space, and  $D$  is the Kahler derivative (the local version of the field derivative in global SUSY). If this were not the case the large SUSY breaking would remain after inflation, giving a gravitino mass (an therefore weak scale) of  $m_{3/2} \sim \mu^2/M_p \sim 10^{14}$  GeV. The second requirement comes from the form of the supergravity potential

$$V = e^K \left( DW \bar{D} W^* - \frac{3}{M_p^2} |W|^2 \right) \quad (7)$$

Since  $DW$  must vanish at the minimum, if  $W(\phi_0) \neq 0$  the cosmological constant is negative after inflation. As spelled out very clearly by Banks, Berkooz, and Steinhardt, if this were the case the universe enters a phase of irreversible contraction.<sup>3</sup> Therefore there must be a special point on moduli space at which  $DW = W = 0$  in the sector responsible for driving inflation. Alternately, the only type of vacua which exit inflation and remain large have this property.<sup>3,13</sup>

Two possibilities for satisfying these requirements have been suggested. The first is to assume that the SUSY breaking responsible for driving inflation arises from the nonperturbative modification of a classical singularity for a composite field.<sup>12</sup> If  $X$  is a composite flat direction made of  $n$  fields, then its Kahler potential has a classical singularity at the origin,  $K = (X^\dagger X)^{1/n}$ . Under some circumstances it is believed that this singularity can be smoothed out (if the composite field satisfies all the t'Hooft anomaly matching conditions at the origin) giving  $K \simeq (X^\dagger X)/\Lambda^{2n-2}$  where  $\Lambda$  is the dynamical scale. In the presence of a superpotential,  $W = \beta X/M_p^{n-3}$ , this leads to SUSY breaking with vacuum energy  $V = \beta^2 \Lambda^{2n-2}/M_p^{2n-6}$ , with  $X = 0$ . At present there is only one known model of this type, but there are probably others.<sup>14</sup> If the coefficient of the superpotential is moduli dependent,  $\beta = \beta(\phi)$ , a potential results over moduli space. However, since  $X = 0$  is the stable point,  $W = 0$  over all of moduli space. The only requirement is then that  $DW$  vanishes at some point, which happens if  $\beta(\phi)$  has a zero. The second suggestion for satisfying the requirements is to assume that a nonperturbative superpotential is generated over moduli space  $W = W(\phi)$ , and that both  $W$  and  $DW$  vanish at some point.<sup>3</sup> As an example, an  $SU(N_c)$  gauge

theory with  $N_f < N_c$  flavors of vector matter transforming in the fundamental gives rise to a nonperturbative superpotential. If the masses of the  $N_f$  flavors are moduli dependent, a nontrivial moduli potential results. If there is an enhanced symmetry point on moduli space,  $\phi_0$ , at which additional flavors become massless such that  $N_f > N_c$ , then  $W(\phi_0) = DW(\phi_0) = 0$  and the above requirements are satisfied in a technically natural way.<sup>3</sup>

As these two examples illustrate, it is possible for an additional SUSY breaking sector (beyond the one required to give the “observed” splitting within the standard model multiplets) to generate an acceptable inflaton potential. It is interesting to note that with the above conditions, the cosmological constant naturally vanishes after inflation; no tuning of the overall zero of the potential is required to exit inflation. It is also natural within moduli inflation to implement the suggestion of Linde and Vilenkin that topological defects can act as seeds for inflation.<sup>15</sup> String moduli transform under modular symmetries and can support topological defects.<sup>13</sup> Finally, for composite flat directions which act as inflatons, the reheat temperature after inflation can in principle be much lower than for standard singlet inflatons.<sup>12</sup>

The dilaton flat direction of string theories has always presented a cosmological dilemma. Since its expectation value is inversely proportional to the gauge coupling constant, its potential goes to zero at large value. This leads to the runaway dilaton problem.<sup>16</sup> Now there must be some barrier for the dilaton between very weak coupling and its true minimum now. Inflation from dynamical SUSY breaking then gives a partial resolution of the problem. In regions of the universe where the dilaton is on the strong coupling side of the barrier, the potential during inflation can in principle keep the dilaton within the basin of attraction of the true minimum. In regions where the dilaton is on the weak coupling side of the barrier it is driven to very weak coupling. The dynamical sector which drives inflation then also gets driven to weak coupling, and successful inflation never completes. The only regions of the universe which undergo sustained inflation and get big are on the strong coupling side. It is also possible (on the strong coupling side) for the dilaton itself to be part of the inflaton direction.<sup>13</sup>

## 5. Conclusions

Supersymmetric flat directions apparently play a important role in the very early universe. In general these directions can lead to the coherent production of scalar condensates. The finite density SUSY breaking has an important impact on the production of such condensates by defining the soft potential at early times. Coherent production of Polonyi type moduli is in general very dangerous, but a number of “solutions” have been proposed, including enhanced symmetry points, additional dynamics to give the fields a large mass, and late inflation. Coherent production of standard model fields can give rise to the baryon asymmetry, and in special cases

dark matter from relic LSPs produced in the decay. Flat directions are also natural candidates to act as inflatons. This generally requires an additional hidden sector which breaks supersymmetry at a very large scale. Supersymmetry must be restored and the superpotential must vanish in this sector at the minimum of the inflaton potential.

Throughout there have been a couple of hints of possible cosmological selection principles. Symmetries can give technically natural solutions to the Polonyi problem and the requirements which must be satisfied by the SUSY breaking sector responsible for inflation. If this is the case, then our vacuum is near a point of enhanced symmetry. This might imply there are additional gauge bosons and/or matter multiplets just above the weak scale (or perhaps some of the ones we see). It also might give a cosmological selection criterion for interesting string vacua. Unfortunately symmetries are not the unique solutions to the above requirements. Even so, we may have glimpses of cosmological selection principles for the type of vacuum in which we live.

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